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A RELIABLE DESIGN AID FOR VAPOUR COMPRESSION CYCLE SYSTEMS

P.J. Hawken, C. Lemal

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A RELIABLE DESIGN AID FOR VAPOUR COMPRESSION CYCLE SYSTEMS

AIDE DE CONCEPTION FIABLE POUR SYSTÈMES À CYCLE DE COMPRESSION DE VAPEUR

P. J. Hawken
C. Lemal

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T. R. Ringer, Head/Chef
Low Temperature Laboratory/
Laboratoire des basses températures

E. H. Dudgeon
Director/
Directeur

ABSTRACT

This paper describes a graphical method that has successfully been used to design air-to-air heat pumps and air conditioners. It is based on manufacturers' data for compressor and heat exchangers and hence is not prone to the problems and complexities associated with a basic theory or performance correlation approach. The method has primarily been used for residential applications but can be extended to include larger sized applications. For ease of implementation, the various compressor and heat exchanger performance curves have been described mathematically and a graphics plotter coupled to a desktop computer has been used to do the drawing necessary. This has speeded up the time involved in using this method by a factor of at least 30.

RESUMÉ

Le document décrit une méthode graphique employée avec succès pour concevoir des pompes à chaleur air-air et des climatiseurs d'air. Cette méthode se fonde sur les données des fabricants sur les compresseurs et les échangeurs de chaleur et n'est donc pas entachée des problèmes et des complexités associés aux méthodes basée sur une théorie fondamentale ou sur une corrélation de rendement. Elle a été employée surtout pour des applications résidentielles mais peut être étendue à des applications de plus grande envergure. Pour faciliter sa mise en oeuvre, les diverses courbes de rendement des compresseurs et des échangeurs de chaleur ont été formulées mathématiquement et le dessin nécessaire peut être fait par un traceur combiné à un ordinateur de table. Ce dernier point a permis de réduire le temps de mise en oeuvre de la méthode d'au moins par un facteur de 30.

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A RELIABLE DESIGN AID FOR VAPOUR COMPRESSION CYCLE SYSTEMS

1.0 INTRODUCTION

A vapour compression (or reverse Rankine) cycle system's steady state performance is essentially a result of the interaction between the evaporator, compressor and condenser. Other hardware items such as connecting lines, expansion valve, suction-to-liquid refrigerant heat exchanger have an effect, but the magnitude of this effect is usually small when compared with the influence of the above three principal components in a vapour compression cycle system. The method presented here offers a valuable aid to sizing these three main components and providing an initial estimate of the system performance in which the designer can have confidence.

The method is essentially graphical in nature and can be done by hand or with the use of a small desktop computer and graphics plotter. Since its development by C. Lemal in the late 1950's, it has been used to design over 20 systems that have been successfully put into production. Air-conditioning, heat pump and refrigeration systems can be designed using this method.

Apart from its simplicity, the attractiveness of this method is that it is based solely on manufacturer's data for the compressor and heat exchangers. Therefore, it does not rely on the application of basic theory to a complex real world situation or the use of correlations based on data that does not describe the situation of interest. It is this feature which gives the method its high credibility as a design aid.

2.0 DESCRIPTION OF METHOD

The four graphs shown in figures 1a, b, c, and d illustrate the method. The system chosen to demonstrate the method is an air-to-air heat pump system; however, the method is not necessarily restricted to air-to-air systems. A start is made with the high pressure, condenser side of the system [Fig. 1a]. For the particular tube size, fin type and spacing chosen for the condenser, an airflow rate and superficial coil face velocity are estimated. Each industry will have its own rules of thumb for choosing coils and air requirements; for example in this case 50 std l/s of air per kW (400 std cfm per ton) of heating required and an air face velocity of 2.29 m/s (450 fpm) are generally used for the "indoor" coil. Using the manufacturer's data for the coil and airflow parameters chosen, curves are drawn for a range of discrete entering air dry bulb temperatures with capacity on the ordinate and refrigerant condensing temperature on the abscissa.

The condenser must reject the heat absorbed by the evaporator plus the power required by the compressor, minus losses. Experience has shown that the losses can be estimated fairly well by a factor of 5% of the compressor capacity. Therefore, over the condenser capacity curves is drawn a map of the heat that must be rejected by the condenser. The compressor manufacturer's data is

used. For each evaporator temperature, 95% of the compressor capacity plus the compressor power requirement is plotted against the condensing temperature. The intersection of the curves for the compressor and the condenser determine possible operating points for the system. A unique operating point is determined by combining the performance of the condenser with that of the evaporator.

Using the same scale for the axes as above, the compressor manufacturer's data is used to plot 95% of the compressor capacity versus condensing temperature for each evaporating temperature on a second graph [Fig. 1b]. On a third graph, using the same vertical scale as the two previous graphs, a plot is made of the evaporator capacity. The type and construction (i.e. tube size, fin construction and number of tube rows) of the evaporator is estimated. Then the airflow rate and superficial coil face velocity are estimated. Using the manufacturer's data, curves are drawn for a range of discrete entering air enthalpies with evaporator capacity on the ordinate and refrigerant evaporating temperature on the abscissa.

With a condenser entering air dry bulb temperature of, say, 20°C (68°F), figure 1a shows that for each evaporating temperature there will be a unique intersection of the compressor curve for that evaporating temperature with the condenser curve for 20°C (68°F) entering air temperature. For each evaporating temperature, the intersection of the relevant compressor curve with the 20°C (68°F) condenser curve is obtained and projected vertically down to the corresponding point on the compressor capacity only curve in figure 1b. These intersections on figure 1b then determine the required evaporator capacity for air entering the condenser at 20°C (68°F) and delineate a range of evaporating and condensing temperatures.

To determine the operating point, each of the above intersections on figure 1b is projected horizontally across to figure 1c until they meet their corresponding evaporating temperature projected up from the abscissa. Joining these intersections then provides a curve which describes the operation of the evaporator for the compressor, condenser and condenser entering air temperature designated. The intersection of this curve with the enthalpy of the air entering the evaporator (40 kJ/kg in this case) then determines the operating point of the evaporator and hence the operating point of the whole system. That is, the evaporating temperature (1.2°C) and heat absorbed by the evaporator (7.3 kW) is given by the relevant intersection on figure 1c. The condensing temperature (48.4°C) is given by projecting the relevant intersection across to the compressor capacity curve on figure 1b and then down to the abscissa. The heat rejected by the condenser (10.2 kW) is given by projecting up from the relevant intersection on figure 1b to the relevant air temperature curve on figure 1a, and then across to the ordinate. Figure 1d shows the interrelationship of figures 1a, 1b and 1c.

Figures 1a,b and c can also be used for preparing capacity and COP versus ambient air temperature curves for a particular design.

3.0 APPLICATION OF METHOD

To date, the major drawback with this method was that it took considerable time to prepare the three graphs. With heat pumps the work involved was nearly doubled as another three graphs had to be prepared for the reverse cycle. During the design development stage, where several iterations on the component specifications are required, two weeks could easily be spent on just working the method.

In order to speed up the design process and hence facilitate the use of this method, the process of preparing the graphs was relegated to a desktop computer and graphics plotter. This meant that what took at least two work days to do by hand could now be done more accurately (and probably more neatly) in less than 30 minutes. By reducing the time involved by a ratio greater than 30:1, this method becomes much more practical and allows a much wider range of component specifications to be considered. Figures 1a, b and c were produced by this method and are shown as produced by the grahics plotter, without any additional embellishment apart from the lines drawn to illustrate the use of the method.

The computer programmes written to accomplish the above, see Appendices A and B, were written in Hewlett-Packard's form of the BASIC language to run on a Hewlett-Packard 9845 computer and Hewlett-Packard 9872 flat-bed plotter. However, with some modification, the programme could run on any system possessing a reasonable level of sophistication.

DATLOD, a separate small programme (Appendix A) is used to store the compressor data from manufacturer's data sheets in the required form on some type of mass storage device (tape, floppy disc or hard disc). This need only be done once for each compressor and consumes the majority of the time required to undertake the computerized version of this method.

The current programme is set up for air-to-air systems and HPDSI, the main programme (Appendix B) accesses three data files - the compressor data file, the evaporator file and the condenser file. The heat exchanger files contain the performance parameters for the commonly used aluminum finned, copper tubed heat exchangers used in the air-conditioning industry. An interactive, question-and-answer session between the user and the computer allows the heat exchanger characteristics and desired compressor to be specified. The programme will then produce the three graphs shown previously.

As the computer used by the authors has an excellent graphics screen and internal, thermal graphics plotter, provision was made in the programme to do the initial development work on the

graphics screen and 'dump' the contents of the screen to the thermal printer. This speeded up the process significantly. Given that the compressor data was already stored, the inputs could now be made and the three graphs prepared on the printer in less than five minutes. When the initial design iterations had been completed and a design had been selected, the three (or six) graphs were prepared on the slower, flat-bed plotter to produce a larger size graph with a more durable and attractive format.

Figure 2 contains a brief flow diagram describing the operation of the main computer programme. Appendix C contains a record of the question-and-answer session required between the computer and the user to produce the graphs in figure 1.

4.0 DESCRIPTION OF COMPUTERIZED APPLICATION

In order to draw the curves for the compressor, condenser and evaporator, the performance of these pieces of hardware must be described mathematically. Compressor data is typically available from the manufacturer in graphical and tabular form, see Appendix D for an example. The separate programme, DATLOD, listed in Appendix A is used to take capacity and power requirement versus evaporating and condensing temperature data for the compressor and to store it on a mass storage device such as a tape cassette or floppy disc. Other data such as the compressor make, model, and refrigerant used is also stored. Currently in North America, compressor data sheets are written in Imperial units, so DATLOD is set up to accept data in this form.

When the main programme, HPDSI, uses this data it will obtain a fourth order polynomial, least squares fit to the data for each evaporating temperature, i.e.

for evaporating temperature, T_E

$$0.95\ Q_E = p_0 + p_1 T_c + p_2 T_c^2 + p_3 T_c^3 + p_4 T_c^4 \qquad (1)$$

and

$$0.95\ Q_E + P = q_0 + q_1 T_c + q_2 T_c^2 + q_3 T_c^3 + q_4 T_c^4 \qquad (2)$$

where T_c is the condensing temperature, Q_E and P are the capacity and power required of the compressor, and p_n and q_n are the constants found for the polynomial fit. The quantities Q_E, T_E and T_c are converted by the programme to SI units from the originally specified Imperial units before the regression is carried out.

These two equations are used to draw the compressor curves in figures 1b and 1a respectively. A second order polynomial was tried but it was decided to use the more accurate fourth order polynomial, as it made little difference in the overall time required to make a run.

The data files for the evaporator and condenser are for conventional, plain copper refrigeration tube with aluminum plate fins. Two tube sizes are included; 10 mm (3/8 inch) with a 25 mm x 22 mm (1.0-inch by 0.866-inch) staggered pattern, and 12 mm (1/2 inch) with a 32 mm x 27 mm (1.25-inch by 1.08-inch) staggered pattern. Fin densities of 390, 470, 550 and 630 fins per metre (10, 12, 14 and 16 fins per inch) were included for each tube size. Tube wall thickness is 0.41 mm (0.016 inch) and the fins are rippled and corrugated 0.15 mm (0.006 inch) thick. The performance data was obtained from relatively old (1950's) brochures supplied by McQuay Inc. of Minneapolis, Minnesota [Ref. 1]. Over many years of use this data base has proved itself to be reliable and to provide close predictions of actual coil performance.

It is assumed that the condenser operates in a dry condition and for a specific tube size and fin density the heat transfer capacity per unit face area (Q_c/A_c) of the condenser with an air face velocity of 2.54 m/s (500 feet per minute) and 2 rows deep is given by:

$$\frac{Q_c}{A_c} = a\,(T_c - T_a) \qquad (3)$$

where T_a is the condenser entering air temperature, a is a constant. Q_c/A_c is multiplied by the correction factor CF_c which allows for the actual air velocity and number of rows of the condenser. For each combination of tube size, fin density and number of tube rows in the direction of airflow, a fourth order, least squares polynomial fit to the data is used to calculate CF_c, i.e.:

$$CF_c = bV_c + cV_c^2 + dV_c^3 + eV_c^4 \qquad (4)$$

where V_c (in m/s) is the superficial face velocity of air to the condenser, and b,c,d and e are constants for the polynomial. For a zero face velocity the correction factor will be zero. This zero data point forced the constant term in the polynomial regression to be so small as to be insignificant in its effect on calculating CF_c. Therefore, to reduce computational efforts, the constant term in polynomial (4) was ignored.

Data for the regression analysis extended up to a face velocity of 3.56 m/s (700 feet per minute). Tables E1 and E2 in Appendix E provide the constants for equations (3) and (4) for R22. The face velocity/row corrections for fin densities of 390 and 470 fins per metre (10 and 12 fins per inch) were so similar that the same corrections were used for both condenser fin densities; similarly for fin densities of 550 and 630 fins per metre (14 and 16 fins per inch).

The evaporator is assumed to operate in a 'wet' condition and for a specific tube size and fin density the heat transfer cap-

acity per unit face area (Q_E/A_E) of the evaporator with a face velocity of 2.54 m/s (500 feet per minute) and 2 rows deep is given by:

$$\frac{Q_E}{A_E} = (fH_a - Q_0) \qquad (5)$$

where $Q_0 = j + k\,T_E + \ell T_E^2$ (6)

As with the condenser, Q_E/A_E is multiplied by the correction factor CF_E which allows for the actual air face velocity and number of rows of the evaporator. For each combination of tube size, fin density and number of tube rows, in the direction of airflow, a fourth order, least squares polynomial fit to the data is used to calculate CF_E, i.e.:

$$CF_E = qV_E + rV_E^2 + sV_E^3 + uV_E^4 \qquad (7)$$

The term Ha (kJ/kg) is the specific enthalpy (-17.8°C (0°F) base) of air entering the evaporator, V_E (m/s) is the superficial face velocity of the air and f, j, k, l, q, r, s and u are constants.

Tables E3 and E4 in Appendix E provide the constants for equations (5), (6) and (7) for R22. The face velocity/row corrections for fin densities of 230, 310 and 390 fins per metre (6, 8 and 10 fins per inch) were so similar that the same corrections were used for all three evaporator fin densities; similarly for evaporator fin densities of 470, 550 and 630 fins per metre (12, 14 and 16 fins per inch). The curve fits for the evaporator were based on evaporating temperatures from -29°C to 13°C (-20°F to 55°F).

The heating, ventilating and air conditioning industries in North America still use Imperial units extensively. The computer programmes were originally written with the industry in mind and hence used Imperial units exclusively. The version of the main program described in this report has been converted to SI units. A version of the program which uses Imperial units is available from the authors.

5.0 CONCLUSIONS

A graphically based design method has been described which has been used successfully for many years to estimate the system performance of various vapour compression cycle systems such as air conditioners and heat pumps. The usefulness of the method as an air-to-air system design aid has been increased tremendously by the development of computer software that allows a desktop computer and plotter to produce the graphs required by the method.

These graphs which previously took at least 16 person hours to complete can now be done in less than 30 minutes on the computer system. This design method can therefore now be used to rapidly examine the effect on the system of a myriad of separate design changes to the compressor and heat exchanger characteristics and thus allow a much greater degree of system optimization.

6.0 REFERENCES

1. -- "Engineering Manual". McQuay, Inc., Minneapolis, Minnesota, curves No. 2087 to 2095, 2249 to 2365, curves dated 1950 to 1958.

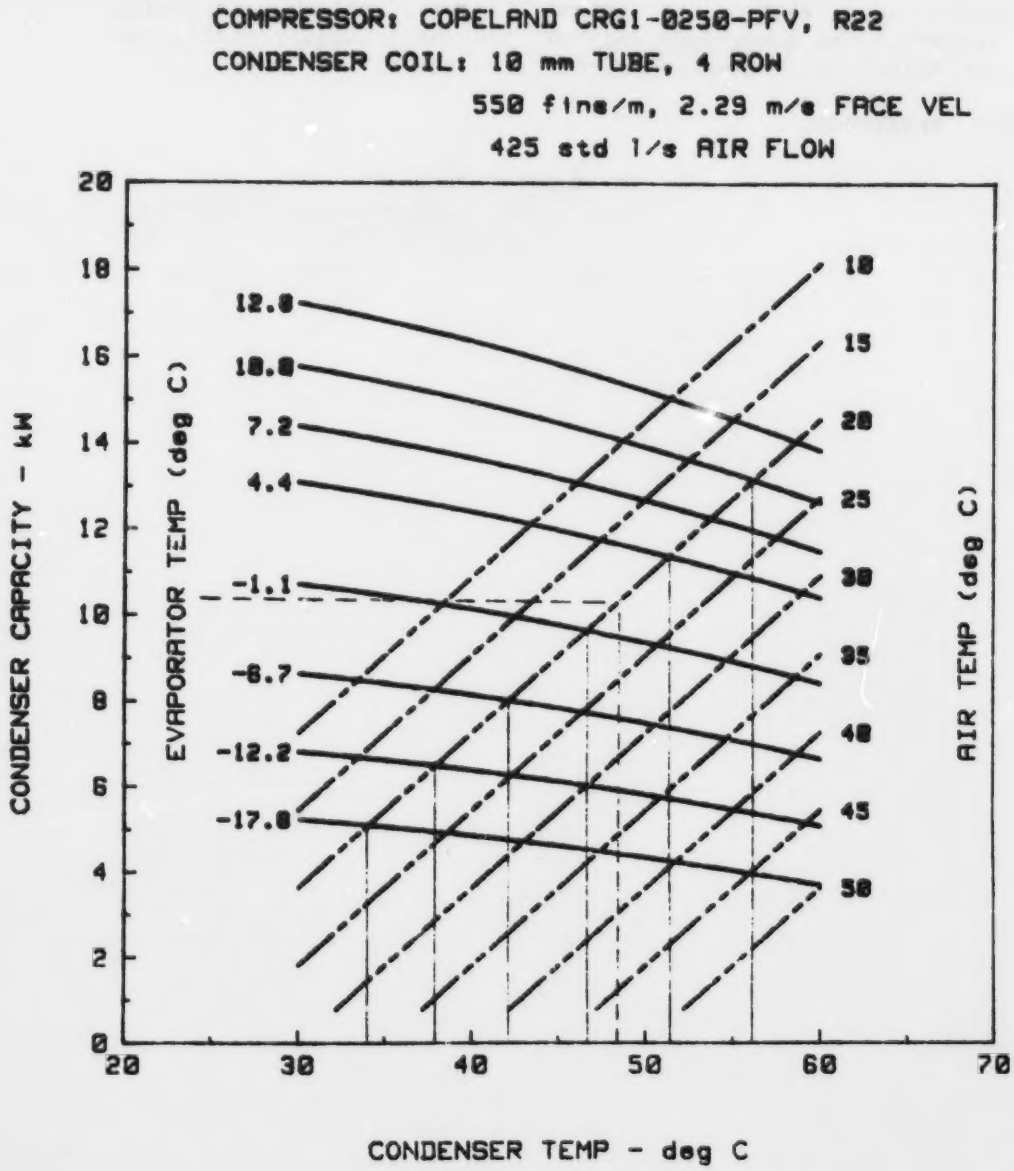

Fig. 1a: Example illustrating the use of the vapour compression cycle system design method - condenser side.

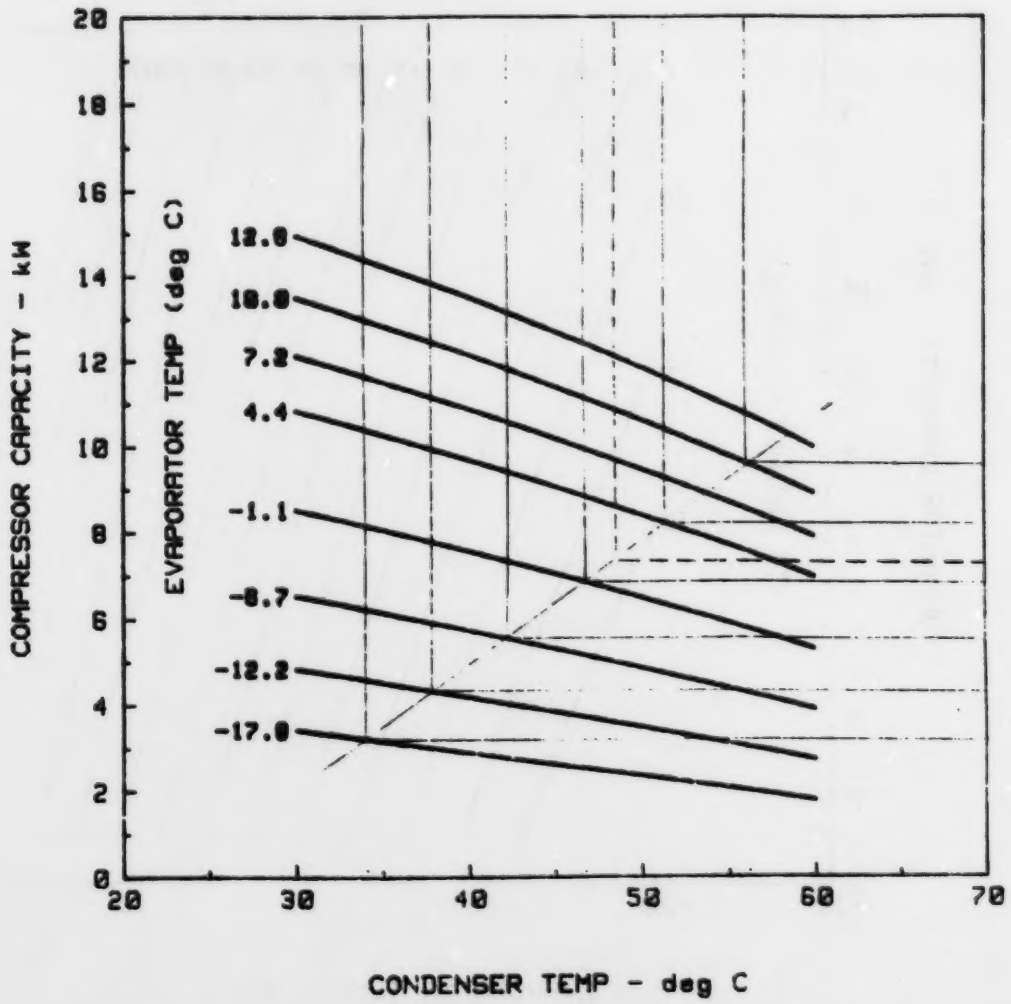

Fig. 1b Example illustrating the use of the vapour compression cycle system design method - compressor capacity only.

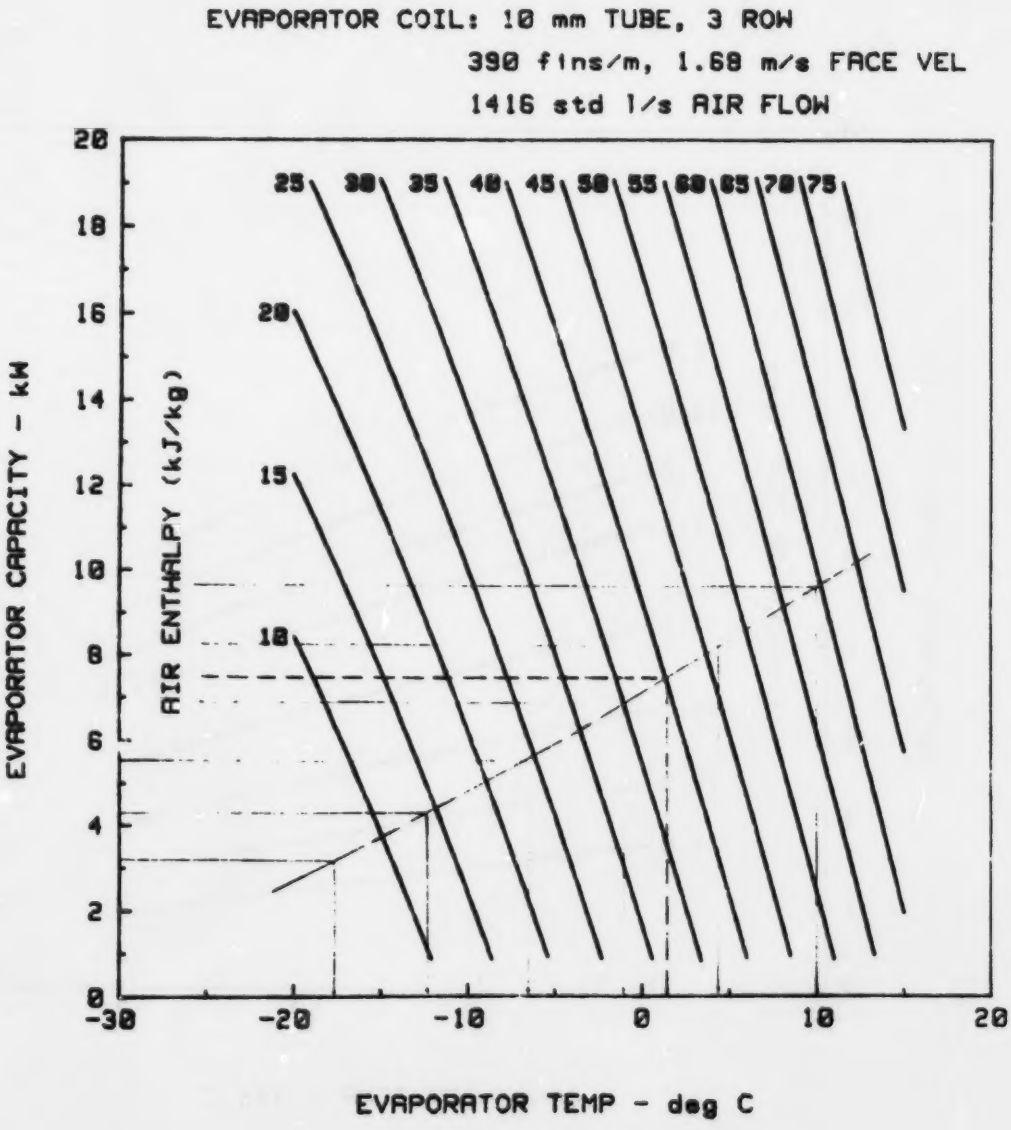

Fig. 1c Example illustrating the use of the vapour compression cycle system design method - evaporator side.

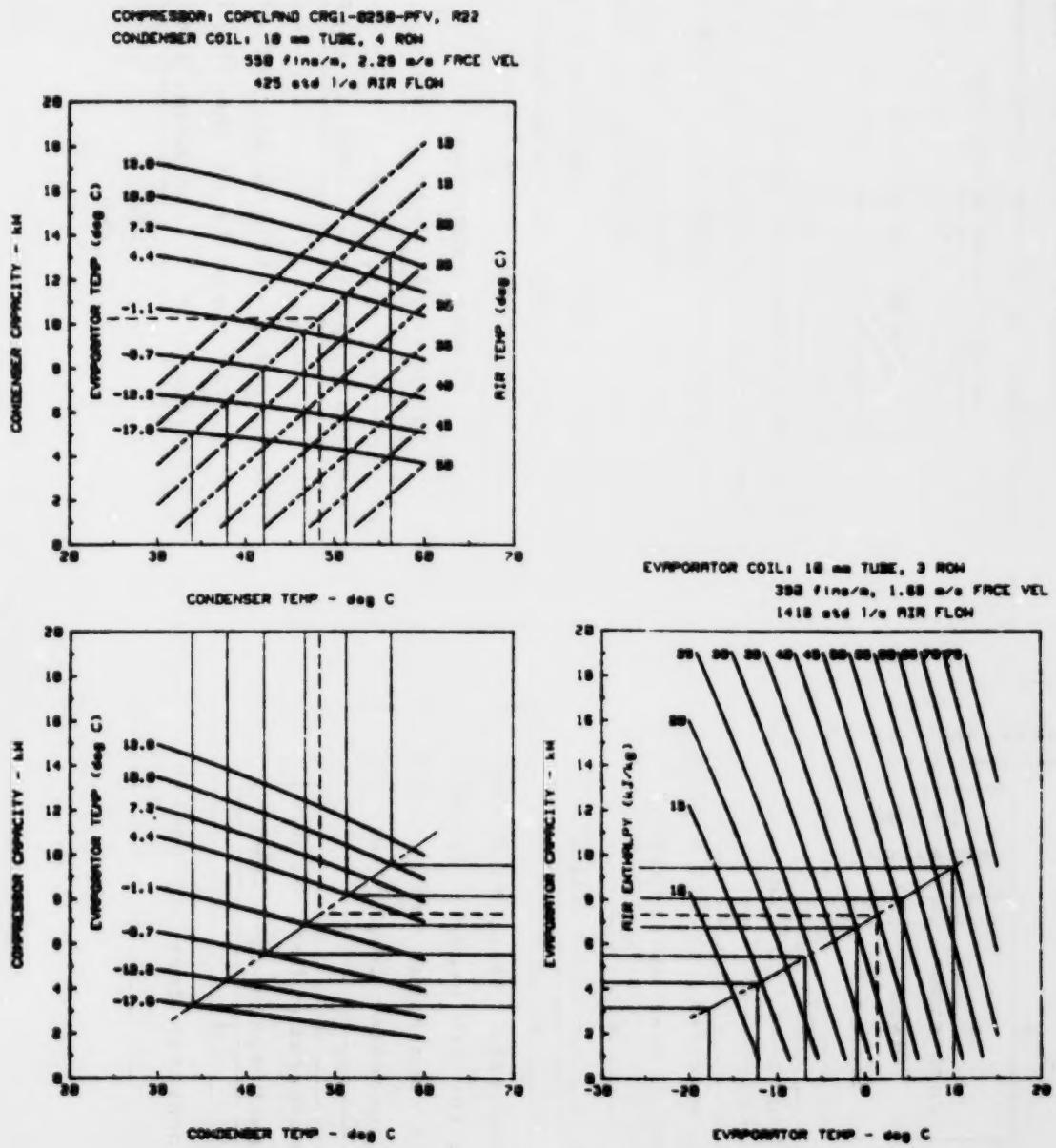
COMPRESSOR: COPELAND CRGI-0250-PFV, R22
CONDENSER COIL: 10 mm TUBE, 4 ROW
550 fins/m, 2.20 m/s FACE VEL
425 std l/s AIR FLOW
CONDENSER CAPACITY - kW
EVAPORATOR TEMP (deg C)
AIR TEMP (deg C)
CONDENSER TEMP - deg C
EVAPORATOR COIL: 10 mm TUBE, 3 ROW
390 fins/m, 1.60 m/s FACE VEL
1410 std l/s AIR FLOW
COMPRESSOR CAPACITY - kW
AIR ENTHALPY (kJ/kg)
EVAPORATOR CAPACITY - kW
EVAPORATOR TEMP - deg C

Fig. 1d Example illustrating the use of the vapour compression cycle system design method - interrelationship of figures 1a, 1b and 1c.

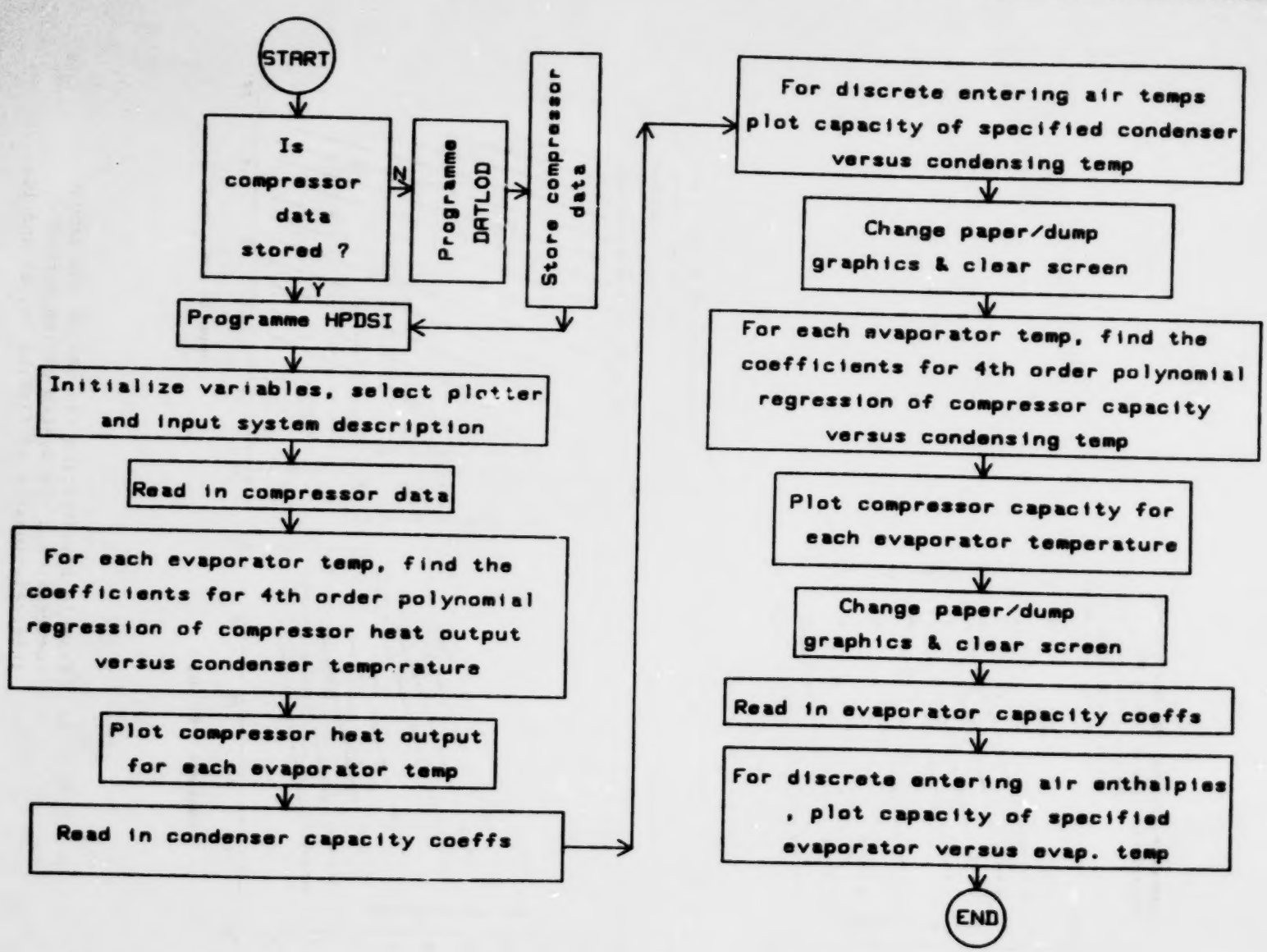
START
Is compressor data stored ?
N
Programme DATLOD
Store compressor data
Y
Programme HPDSI
Initialize variables, select plotter and input system description
Read in compressor data
For each evaporator temp, find the coefficients for 4th order polynomial regression of compressor heat output versus condenser temperature
Plot compressor heat output for each evaporator temp
Read in condenser capacity coeffs
For discrete entering air temps plot capacity of specified condenser versus condensing temp
Change paper/dump graphics & clear screen
For each evaporator temp, find the coefficients for 4th order polynomial regression of compressor capacity versus condensing temp
Plot compressor capacity for each evaporator temperature
Change paper/dump graphics & clear screen
Read in evaporator capacity coeffs
For discrete entering air enthalpies , plot capacity of specified evaporator versus evap. temp
END

Fig. 2 Flow chart of computer programmes used to apply the system design method.

APPENDIX A

LISTING OF COMPUTER PROGRAMME (DATLOD) TO CREATE COMPRESSOR PERFORMANCE DATA FILES

```
10  ! ********************************************************************************
20  !
30  ! THIS PROGRAM STORES COMPRESSOR DATA (IMPERIAL UNITS) ON DISC
40  !   FOR LATER USE
50  !
60  ! DATA LOAD PROGRAM (DATLOD)
70  !
80  ! P. Hawken       June 27, 1984
90  !
100 ! ********************************************************************************
110 !
120   OPTION BASE 1
130   PRINTER IS 16
140   PRINT "THIS PROGRAM STORES COMPRESSOR DATA (IMPERIAL UNITS) ON DISC FOR LA
TER USE"
150 ! ..............................................................
160 !  INTIALIZING AND SETTING UP DATA FILE
170 ! ..............................................................
180   LINPUT "File name for data file ?",File_name$
190   LINPUT "Mass storage type and select code,eg. H8,0,0 ?",Spec$
200   File_name$=TRIM$(File_name$)
210   Spec$=TRIM$(Spec$)
220   CREATE File_name$&":"&Spec$,100,32
230   ASSIGN @1 TO File_name$&":"&Spec$
240 ! ..............................................
250 !  INPUT VALUES
260 ! ..............................................
270   LINPUT "Compressor manufacturer?",Comp_man$
280   LINPUT "Compressor model number?",Comp_model$
290   LINPUT "Refrigerant?",Refrig$
300   INPUT "Number of evaporator temps ?",Net
310   INPUT "Number of condenser temps ?",Nct
320 !
330   DIM Comp_curve(88,4)
340   PRINT ""
350   PRINT "Enter compressor data in the following order: "
360   PRINT "Evap temp (deg F), cond temp (deg F),compressor capacity (Btu/hr) a
nd power (Watts)"
370   PRINT "Start with lowest temps first and for each evap temp enter all cond
 temps"
380   PRIN  "and associated capacity and power values before going on to next ev
ap temp."
390   PRINT "If no value exists, enter -1 ."
400   PRINT "Wait for prompts"
410   Nrows=Net*Nct
420   Nrows=INT(Nrows)
430   MAT INPUT Comp_curve(Nrows,4)
440   PRINT PAGE
450 ! ..................................
460 !  ECHO DATA
470 ! ..................................
480   PRINTER IS 0
490   PRINT Comp_man$
500   PRINT Comp_model$
510   PRINT Refrig$
520   PRINT Net;Nct
530   MAT PRINT Comp_curve;
```

```
540 ! ....................................
550 !   CORRECTIONS
560 ! ....................................
570   INPUT "IS data correct (Y/N)?",Ans1$
580   IF Ans1$="YES" THEN Exit
590   IF Ans1$="Y" THEN Exit
600 Correct1:   INPUT "Is manufacturer,model and refrigerant data correct (Y/N)?
",Ans2$
610   IF Ans2$="Y" THEN GOTO Correct2
620   INPUT "Compressor manufacturer ?",Comp_man$
630   INPUT "Compressor model number ?",Comp_model$
640   INPUT "Refrigerant ?",Refrig$
650 Correct2:   INPUT "Are number of evaporator and condenser temperatures corre
ct (Y/N)?",Ans3$
660   IF Ans3$="Y" THEN GOTO Correct3
670   INPUT "Number of evaporator temps ?",Net
680   INPUT "Number of condenser temps ?",Nct
690 Correct3:   INPUT "Do you wish to correct a data value (Y/N)?",Ans4$
700   IF Ans4$="N" THEN GOTO Exit
710   INPUT "Row number of correction ?",Nr
720   Nr=INT(Nr)
730   IF (Nr>0) AND (Nr<=Nrows) THEN 760
740   GOSUB Message1
750   GOTO 710
760   INPUT "Column number of correction ?",Nc
770   Nc=INT(Nc)
780   IF (Nc>0) AND (Nc<=4) THEN 810
790   GOSUB Message1
800   GOTO 760
810   PRINT "Row No";Nr;"  Column No";Nc;"   Old value = ";Comp_curve(Nr,Nc)
820   INPUT "Correct value = ?",Comp_curve(Nr,Nc)
830   PRINT "Row No";Nr;"  Column No",Nc;"   Correct value = ";Comp_curve(Nr,Nc)
840   INPUT "Further corrections?",Ans5$
850   IF Ans5$="YES" THEN 710
860   IF Ans5$="Y" THEN 710
870   PRINT USING "///"
880   PRINT Comp_man$
890   PRINT Comp_model$
900   PRINT Refrig$
910   PRINT Net;Nct
920   MAT PRINT Comp_curve;
930   ! ....................................
940   ! STORE DATA
950   ! ....................................
960 Exit:  PRINT #1;Comp_man$
970   PRINT #1;Comp_model$
980   PRINT #1;Refrig$
990   PRINT #1;Net,Nct
1000  MAT PRINT #1;Comp_curve
1010  PRINT "DATA STORED AS ";File_name$;" ON DEVICE ";Spec$
1020  PRINTER IS 16
1030 ! ....................
1040 ! CLOSE DATA FILE
1050 ! ....................
1060  ASSIGN #1 TO *
1070  END
1080 Message1:   BEEP
1090  DISP "Improper response--please try again."
1100  WAIT 3000
1110  RETURN
```

APPENDIX B

LISTING OF THE MAIN COMPUTER PROGRAMME (HPDSI) TO PRODUCE THE GRAPHS REQUIRED BY THE DESIGN METHOD

```
10  ! ********************************************************************************
20  ! PROGRAMME "HPDSI"
30  !
40  ! AIR-TO-AIR HEAT PUMP AND AIR-CONDITIONER DESIGN PROGRAMME
50  !  COMPRESSOR DATA FILES PREPARED BY PROGRAMME "DATLOD".
60  !  IT IS  ASSUMED THAT THE DATA IN 'DATLOD' IS IN IMPERIAL UNITS.
70  ! HEAT EXCHANGER PERFORMANCE DATA IS INTERNAL AND ON DATA FILES
80  !  "CONDSI","EVP1SI" AND "EVP2SI"
90  !
100 ! P. Hawken     Nov, 1983          REVISION   Sept 11,1984
110 !
120 ! ********************************************************************************
130 !
140 !
150   ! ************************************************************
160   !  INITIALIZATION
170   ! ************************************************************
180   OPTION BASE 1
190   PRINTER IS 16
200   !
210   ! GRAPHICS BANNER FOR CRT
220   !
230   PLOTTER IS 13,"GRAPHICS"
240   GRAPHICS
250   IMAGE K,/,K,/,K,/,K,/,K
260   PEN 2
270   CSIZE 5,.6,0
280   LORG 1
290   MOVE 0,70
300   LABEL USING 250;"THIS PROGRAM WILL ASSIST WITH","HEAT PUMP AND AIR-","COND
ITIONER DESIGN","COMPRESSOR DATA MUST BE ","PREPARED BY PROGRAMME 'DATLOD'"
310   LABEL USING 250;"FROM IMPERIAL UNITS","RESULTS ARE PRESENTED IN SI UNITS"
320   CSIZE 3.3
330   LABEL USING "//,K";"P. Hawken   Nov,1983    REVISION  Sept 11,1984"
340   WAIT 7000
350   EXIT GRAPHICS
360   PLOTTER 13 IS OFF
370   !
380   ! DIMENSIONING AND INITIALIZING ARRAYS
390   !
400   DIM Comp_curve(120,4)
410   DIM D(4,120)
420   DIM X(0:4,0:4),P(0),B(0:4)
430   DIM Coeff(14,0:4)
440   DIM Xname$[25],Yname$[25]
450   MAT Comp_curve=ZER
460   !
470   ! SELECTING AND INITIALIZING PLOTTER
480   !
490   INPUT "DO YOU WISH TO USE THE 9872A AS THE PLOTTER?(Y/N)",Plotter$
500   IF Plotter$="N" THEN GOTO 530
510   PLOTTER IS 7,5,"9872A"
520   GOTO 550
530   PLOTTER IS 13,"GRAPHICS"
540   GRAPHICS
550   RAD
```

```
560   !
570   ! INPUT SYSTEM DESCRIPTION
580   !
590   INPUT "FILE NAME OF COMPRESSOR PERFORMANCE DATA FILE ?",Comp_file$
600   INPUT "CONDENSER COIL TUBE SIZE,i.e. 10 OR 12 mm ?",Tube_dia_cnd
610   INPUT "No OF ROWS FOR CONDENSER COIL,i.e. 1 TO 6 ?",N_rows_cnd
620   INPUT "CONDENSER COIL ,No of fins per metre i.e.390,470,550 OR 630 ?",N_fp
m_cnd
630   INPUT "FACE VEL OF AIR TO CONDENSER COIL (m/s) ?",Face_vel_cnd
640   INPUT "VOLUMETRIC FLOW RATE OF AIR TO CONDENSER COIL (std l/s) ?",Air_flow
_cnd
650   INPUT "EVAPORATOR COIL TUBE SIZE,i.e. 10 OR 12 mm ?",Tube_dia_evp
660   INPUT "No OF ROWS IN EVAPORATOR COIL,i.e. 1 TO 6 ?",N_rows_evp
670   INPUT "EVAPORATOR COIL ,No of fins per metre ,i.e. 390,470,550 OR 630?",N_
fpm_evp
680   INPUT "FACE VEL OF AIR TO EVAPORATOR COIL (m/s) ?",Face_vel_evp
690   INPUT "VOLUMETRIC FLOW RATE OF AIR TO EVAPORATOR COIL (std l/s) ?",Air_flo
w_evp
700   !
710   !  ECHO AND CHECK SYSTEM DESCRIPTION
720   !
730   Blank$="           "
740   PRINTER IS 0
750   PRINT "COMPRESSOR:"
760   PRINT
770   PRINT Blank$;"Compressor data file is ";Comp_file$
780   PRINT
790   PRINT "CONDENSER:"
800   PRINT Blank$;"tube diameter is ";Tube_dia_cnd;" mm"
810   PRINT Blank$;N_rows_cnd;" rows deep"
820   PRINT Blank$;N_fpm_cnd;" fins per metre"
830   PRINT Blank$;"air face velocity is ";Face_vel_cnd;" m/s"
840   PRINT Blank$;"air flow rate is ";Air_flow_cnd;" std l/s"
850   PRINT
860   PRINT "EVAPORATOR:"
870   PRINT Blank$;"tube diameter is ";Tube_dia_evp;" mm"
880   PRINT Blank$;N_rows_evp;" rows deep"
890   PRINT Blank$;N_fpm_evp;" fins per metre"
900   PRINT Blank$;"air face velocity is ";Face_vel_evp;" m/s"
910   PRINT Blank$;"air flow rate is ";Air_flow_evp;" std l/s"
920   PRINTER IS 16
930   INPUT "IS SYSTEM SPECIFIED CORRECTLY (Y/N)?",Ans1$
940   IF Ans1$="N" THEN GOTO 560
950   !
960   ! READ IN COMPRESSOR DATA FILE
970   !
980   ASSIGN @1 TO Comp_file$&":H8,1,0"
990   READ @1;Comp_man$
1000  READ @1;Comp_model$
1010  READ @1;Refrig$
1020  READ @1;Net,Nct
1030  Nrows=Net*Nct
1040  MAT READ @1;Comp_curve(Nrows,4)
1050  REDIM D(4,Nrows)
```

```
1060 ! ************************************************************
1070 !   CONDENSER CAPACITY AND COMPRESSOR HEAT DELIVERY
1080 ! ************************************************************
1090  Flag1=0
1100  Flag2=0
1110  Flag3=0
1120  Flag4=0
1130  Xrow=2
1140  Yrow=4
1150  Xname$="CONDENSER TEMP - deg C"
1160  Yname$="CONDENSER CAPACITY - kW"
1170  Fam_name1$="EVAPORATOR TEMP (deg C)"
1180  Fam_name2$="AIR TEMP (deg C)"
1190  Coil$="CONDENSER COIL:"
1200  Tube_dia=Tube_dia_cnd
1210  N_rows=N_rows_cnd
1220  N_fpm=N_fpm_cnd
1230  Face_vel=Face_vel_cnd
1240  Air_flow=Air_flow_cnd
1250  Ipen=2
1260  Num_dig$="M2D.D"
1270  Xmin=PROUND((Comp_curve(1,2)-15-32)*5/9,1)
1280  Xmax=70
1290  Ymin=0
1300  INPUT "Maximum energy flow rate(kW) for ordinate,Ymax  (Ymin=0)?",Ymax
1310  IF Plotter$="N" THEN GOTO 1380
1320  LIMIT 10,187,40,250
1330  PRINT USING "2/,80A";"SET UP PLOTTING LIMITS ON PLOTTER"
1340  PRINT USING "80A";"ALLOW 5 MAJOR DIVISIONS ON THE HORIZONTAL AXIS"
1350  PRINT USING "80A,2/";"LENGTH OF VERT AXIS DEPENDS ON YMAX (YMIN=0)"
1360  LOCATE
1370  GOTO 1390
1380  LOCATE 13.3,106.7,7.3,87.7
1390  SCALE Xmin,Xmax,Ymin,Ymax
1400  FOR L=1 TO Net
1410  FOR K=1 TO Nct
1420  Q=K+(L-1)*Nct
1430  D(1,K)=(Comp_curve(Q,1)-32)*5/9                          !EVAPORATING TEMP
1440  D(2,K)=(Comp_curve(Q,2)-32)*5/9                  ! CONDENSING TEMPERATURE
1450  D(3,K)=.95*Comp_curve(Q,3)*2.93071E-4                          ! CAPACITY
1460  D(4,K)=(.95*Comp_curve(Q,3)*.293071+Comp_curve(Q,4))/1000      !CAP&WATTS
1470  NEXT K
1480  GOSUB Poly
1490  C0=Coeff(L,0)
1500  C1=Coeff(L,1)
1510  C2=Coeff(L,2)
1520  Xinit=PROUND(D(2,1),1)
1530  Xfinal=PROUND(D(2,Nct),1)
1540  Curve_name=DROUND(D(1,1),3)
1550  Label_datum=0
1560  Xcurv_nam_pos=Xinit-.5
1570  LINE TYPE 1
1580  GOSUB Plot
1590  NEXT L
```

```
1600  DIM Cond_data(2,2,6,4)
1610  DIM K1(2,5:8)
1620  Area_cnd=Air_flow_cnd/Face_vel_cnd/1000
1630  Idia=2
1640  IF Tube_dia_cnd<11 THEN Idia=1
1650  DATA 1.0045,1.1753,1.2378,1.3003,1.1697,1.2435,1.3400,1.4195
1660  MAT READ K1
1670  U1_cnd=K1(Idia,DROUND(N_fpm_cnd/78.7402,1))
1680  ASSIGN @2 TO "CONDSI:H8,1,0"
1690  MAT READ @2;Cond_data
1700  I_fpm=1
1710  IF N_fpm_cnd>500 THEN I_fpm=2
1720  B1=Cond_data(Idia,I_fpm,N_rows_cnd,1)
1730  B2=Cond_data(Idia,I_fpm,N_rows_cnd,2)
1740  B3=Cond_data(Idia,I_fpm,N_rows_cnd,3)
1750  B4=Cond_data(Idia,I_fpm,N_rows_cnd,4)
1760  U2_cnd=B1*Face_vel_cnd+B2*Face_vel_cnd^2+B3*Face_vel_cnd^3+B4*Face_vel_cnd
^4
1770  Ua_cnd=U1_cnd*U2_cnd*Area_cnd
1780  Ipen=3
1790  Label_datum=2
1800  Xcurv_nam_pos=Xfinal+.5
1810  Flag2=1
1820  C2=0
1830  C1=Ua_cnd
1840  FOR Air_temp=10 TO 50 STEP 5
1850  C0=-Ua_cnd*Air_temp
1860  Curve_name=Air_temp
1870  LINE TYPE 0
1880  GOSUB Plot
1890  NEXT Air_temp
1900  PEN 1
1910  IF Plotter$="Y" THEN GOTO 1970
1920  PRINT USING "2/,80A,2/";"PRESS "&CHR$(129)&CHR$(138)&"CONT"&CHR$(128)&CHR$
(136)&" BUTTON WHEN READY"
1930  PAUSE
1940  PLOTTER IS "GRAPHICS"
1950  GRAPHICS
1960  LOCATE 13.3,106.7,7.3,87.7
1970  PRINT PAGE
```

```
1980  ! ************************************************
1990  !    CAPACITY OF COMPRESSOR ONLY
2000  ! ************************************************
2010  Xrow=2
2020  Yrow=3
2030  Flag1=0
2040  Flag2=0
2050  Flag3=1
2060  Flag4=0
2070  Xname$="CONDENSER TEMP - deg C"
2080  Yname$="COMPRESSOR CAPACITY - kW"
2090  Fam_name1$="EVAPORATOR TEMP (deg C)"
2100  Fam_name2$=""
2110  Ipen=2
2120  Num_dig$="M2D.D"
2130  LINE TYPE 1
2140  PRINTER IS 16
2150  IF Plotter$="N" THEN GOTO 2200
2160  PRINT USING "2/,80A,/,80A";"CHANGE PAPER AND ","SET UP PLOTTING LIMITS ON
PLOTTER"
2170  PRINT USING "80A,2/";"ALLOW 5 MAJOR DIVISIONS ON THE HORIZONTAL AXIS"
2180  LOCATE
2190  PRINT PAGE
2200  SCALE Xmin,Xmax,Ymin,Ymax
2210  FOR L=1 TO Net
2220  FOR K=1 TO Nct
2230  Q=K+(L-1)*Nct
2240  D(1,K)=(Comp_curve(Q,1)-32)*5/9
2250  D(2,K)=(Comp_curve(Q,2)-32)*5/9
2260  D(3,K)=.95*Comp_curve(Q,3)*2.93071E-4
2270  D(4,K)=(.95*Comp_curve(Q,3)*.293071+Comp_curve(Q,4))/1000
2280  NEXT K
2290  GOSUB Poly
2300  C0=Coeff(L,0)
2310  C1=Coeff(L,1)
2320  C2=Coeff(L,2)
2330  Xinit=PROUND(D(2,1),1)
2340  Xfinal=PROUND(D(2,Nct),1)
2350  Curve_name=DROUND(D(1,1),3)
2360  Label_datum=0
2370  Xcurv_nam_pos=Xinit-.5
2380  LINE TYPE 1
2390  GOSUB Plot
2400  NEXT L
2410  PEN 1
2420  IF Plotter$="Y" THEN GOTO 2480
2430  PRINT USING "2/,80A,2/";"PRESS THE "&CHR$(129)&CHR$(138)&"CONT"&CHR$(128)&
CHR$(136)&" BUTTON WHEN READY"
2440  PAUSE
2450  PLOTTER IS "GRAPHICS"
2460  GRAPHICS
2470  LOCATE 13.3,106.7,7.3,87.7
2480  PRINT PAGE
```

```
2490   ! **********************************************************
2500   !  EVAPORATOR CAPACITY
2510   ! **********************************************************
2520   Flag1=0
2530   Flag2=0
2540   Flag3=0
2550   Flag4=1
2560   Xmin=-30
2570   Xmax=20
2580   Ymin=0
2590   Xname$="EVAPORATOR TEMP - deg C"
2600   Yname$="EVAPORATOR CAPACITY - kW"
2610   Fam_name2$=""
2620   DIM Fam_name1$[25]
2630   Fam_name1$="AIR ENTHALPY (kJ/kg)"
2640   Coil$="EVAPORATOR COIL:"
2650   Ipen=2
2660   Num_dig$="M2D"
2670   IF Plotter$="N" THEN GOTO 2720
2680   PRINT USING "2/,80A,/,80A";"CHANGE PAPER AND","SET UP PLOTTING LIMITS ON P
LOTTER"
2690   PRINT USING "80A";"ALLOW 5 MAJOR DIVISIONS ON HORIZONTAL AXIS"
2700   PRINT USING "80A,2/";"LENGTH OF VERT AXIS IS AS BEFORE"
2710   LOCATE
2720   SCALE Xmin,Xmax,Ymin,Ymax
2730   DIM Evap_data(2,2,6,4)
2740   DIM K2(2,5:8,4)
2750   Area_evp=Air_flow_evp/Face_vel_evp/1000
2760    Idia=2
2770    IF Tube_dia_evp<11 THEN Idia=1
2780    ASSIGN @3 TO "EVP1SI:H8,1,0"
2790    ASSIGN @4 TO "EVP2SI:H8,1,0"
2800    MAT READ @3;K2
2810    MAT READ @4;Evap_data
2820    R1=K2(Idia,DROUND(N_fpm_evp/78.7402,1),1)
2830    R2=K2(Idia,DROUND(N_fpm_evp/78.7402,1),2)
2840    R3=K2(Idia,DROUND(N_fpm_evp/78.7402,1),3)
2850    R4=K2(Idia,DROUND(N_fpm_evp/78.7402,1),4)
2860    I_fpm=1
2870    IF N_fpm_evp>400 THEN I_fpm=2
2880    Cf1=Evap_data(Idia,I_fpm,N_rows_evp,1)
2890    Cf2=Evap_data(Idia,I_fpm,N_rows_evp,2)
2900    Cf3=Evap_data(Idia,I_fpm,N_rows_evp,3)
2910    Cf4=Evap_data(Idia,I_fpm,N_rows_evp,4)
2920    Corr_fact=Cf1+Face_vel_evp+Cf2*Face_vel_evp^2+Cf3*Face_vel_evp^3+Cf4*Face
_vel_evp^4
2930    Mfact=Corr_fact*Area_evp
2940    C1=R3*Mfact
2950    C2=R4*Mfact
2960     Xinit=-20
2970     Xfinal=15
2980     Tube_dia=Tube_dia_evp
2990     N_rows=N_rows_evp
3000     N_fpm=N_fpm_evp
3010     Face_vel=Face_vel_evp
3020     Air_flow=Air_flow_evp
3030     Xcurv_nam_pos=Xinit-.5
3040     Label_datum=0
3050     Ipen=4
3060     FOR Hair=10 TO 75 STEP 5
3070     LINE TYPE 1
3080     GOSUB Evapdraw
3090     NEXT Hair
```

```
3100 !  Hair=12.68
3110 !  Xcurv_nam_pos=Xinit-.2
3120 !  LINE TYPE 5
3130 !  GOSUB Evapdraw
3140 !  Hair=38.84
3150 !  LINE TYPE 5
3160 !  GOSUB Evapdraw
3170  PEN 0
3180  IF Plotter$="Y" THEN GOTO 3220
3190  PRINT USING "2/,80A,2/,";"PRESS THE "&CHR$(129)&CHR$(138)&"CONT"&CHR$(128)
&CHR$(136)&" BUTTON WHEN FINISHED"
3200  PAUSE
3210  EXIT GRAPHICS
3220  PRINT PAGE
3230  PLOTTER 13 IS OFF
3240  IF Plotter$="Y" THEN PLOTTER 7,5 IS OFF
3250  STOP
3260 Evapdraw:  C0=(R1+Hair+R2)*Mfact
3270  Curve_name=Hair
3280  GOSUB Plot
3290  RETURN
3300 ! ************************************************************
3310 ! FIND COEFFICIENTS FOR POLYNOMIAL CURVE FIT TO THE
3320 !    COMPRESSOR DATA
3330 ! ************************************************************
3340 Poly: MAT X=ZER
3350  MAT P=ZER
3360  Deg=2
3370  FOR I=1 TO Nct
3380  IF D(Yrow,I)<0 THEN GOTO 3470
3390  X(0,0)=X(0,0)+1
3400  X(0,Deg+1)=X(0,Deg+1)+D(Yrow,I)
3410  X(Deg+1,Deg+1)=X(Deg+1,Deg+1)+D(Yrow,I)^2
3420  FOR J=1 TO Deg
3430  P(J)=P(J)+D(Xrow,I)^J
3440  X(J,Deg+1)=X(J,Deg+1)+D(Yrow,I)*D(Xrow,I)^J
3450  P(Deg+J)=P(Deg+J)+D(Xrow,I)^(Deg+J)
3460  NEXT J
3470  NEXT I
3480  FOR I=0 TO Deg
3490  FOR J=I+(I=0) TO Deg
3500  X(I,J)=P(I+J)
3510  NEXT J
3520  NEXT I
3530  Nobs=X(0,0)
3540  X(0,0)=SQR(X(0,0))
3550  FOR I=1 TO Deg+1
3560  X(0,I)=X(0,I)/X(0,0)
3570  NEXT I
3580  FOR I=1 TO Deg
3590  FOR J=1 TO Deg+1
3600   IF I<>J THEN 3690
3610   FOR M=0 TO I-1
3620   X(I,I)=X(I,I)-X(M,I)^2
3630   NEXT M
```

```
3640   IF X(I,I)>0 THEN 3670
3650   PRINT "Specified maxinum degree is too large for computational accuracy!"
3660   STOP
3670   X(I,I)=SQR(X(I,I))
3680   GOTO 3730
3690   FOR M=0 TO I-1
3700   X(I,J)=X(I,J)-X(M,I)*X(M,J)
3710   NEXT M
3720   X(I,J)=X(I,J)/X(I,I)
3730   NEXT J
3740   NEXT I
3750   FOR I=0 TO Deg
3760   X(I,I)=1/X(I,I)
3770   NEXT I
3780   FOR I=Deg-1 TO 0 STEP -1
3790   FOR J=Deg TO I+1 STEP -1
3800   Dum=0
3810   FOR N=I+1 TO J
3820   Dum=Dum+X(I,N)*X(N,J)
3830   NEXT N
3840   X(I,J)=-Dum*X(I,I)
3850   NEXT J
3860   NEXT I
3870  MAT Coeff=ZER
3880  ! PRINT USING "2X,3D,2X,16A,/";D(1,1);"DEG F EVAP TEMP"
3890  FOR I=0 TO Deg
3900  FOR J=I TO Deg
3910  Coeff(L,I)=Coeff(L,I)+X(I,J)*X(J,Deg+1)
3920  NEXT J
3930  IF I=0 THEN Dum$="'CONSTANT'"
3940  IF I<>0 THEN Dum$="X^"&VAL$(I)
3950  ! PRINT USING "10A,,4X,M7D.5D,1X,M.12DE";Dum$,Coeff(L,I),Coeff(L,I)
3960  NEXT I
3970  RETURN
3980  ! ************************************************************************
3990  !      PLOTTING SUBROUTINE
4000  ! ************************************************************************
4010 Plot:  !
4020  IF Flag1<1 THEN GOSUB Labels
4030  PEN Ipen
4040  FOR X=Xinit TO Xfinal STEP .1
4050  Y=C0+C1*X+C2*X*X
4060  IF X=Xinit THEN MOVE X,Y
4070  IF X=Xinit THEN Ycurv_nam_pos=Y
4080  Pen_cont=-1
4090  IF Y<Ymax-(Ymax-Ymin)/20 THEN GOTO 4120
4100  Ycurv_nam_pos=Ymax-(Ymax-Ymin)/20
4110  Xcurv_nam_pos=X-.5
4120  IF (Y<Ymin+(Ymax-Ymin)/24) OR (Y>Ymax-(Ymax-Ymin)/20) THEN Pen_cont=-2
4130  PLOT X,Y,Pen_cont
4140  NEXT X
4150  CSIZE 2.2
4160  LDIR 0
4170  LORG Label_datum
4180  LINE TYPE 1
4190  IF Flag2>0 THEN Ycurv_nam_pos=Y
4200  IF Ycurv_nam_pos>Ymax-(Ymax-Ymin)/60 THEN Ycurv_nam_pos=Ymax*10
4210  IF (Flag2<1) AND (Y>=Ymax) THEN Ycurv_nam_pos=Ymax*10
4220  MOVE Xcurv_nam_pos,Ycurv_nam_pos
4230  LABEL USING Num_dig$;Curve_name
4240  RETURN
```

```
4250  !
4260  !  LABELLING OF GRAPH
4270  !
4280 Labels:  PEN 1
4290  CSIZE 2.5
4300  IF Plotter$="N" THEN CSIZE 3.3
4310  FRAME
4320  LAXES 5,1,Xmin,0,-2,2
4330  FRAME
4340  FRAME
4350  IF Plotter$="N" THEN SETGU
4360  MOVE Xmin+(Xmax-Xmin)/10,Ymax+(Ymax-Ymin)*11/60
4370  IF Plotter$="N" THEN MOVE 15,97.3
4380  LORG 1
4390  IF Flag4>0 THEN GOTO 4410
4400  LABEL USING "K,K,X,K,K,X,K";"COMPRESSOR: ",Comp_man$,Comp_model$,",",Refri
g$
4410  MOVE Xmin+(Xmax-Xmin)/10,Ymax+(Ymax-Ymin)*8/60
4420  IF Plotter$="N" THEN MOVE 15,94.4
4430  IF Flag3>0 THEN GOTO 4510
4440  LABEL USING "K,X,2D,X,K,K,X,D,X,K";Coil$,Tube_dia,"mm TUBE",",",N_rows,"RO
W"
4450  MOVE Xmin+(Xmax-Xmin)*4/10,Ymax+(Ymax-Ymin)*5/60
4460  IF Plotter$="N" THEN MOVE 38.5,91.5
4470  LABEL USING "3D,X,K,K,X,D.2D,X,K";N_fpm,"fins/m",",",Face_vel,"m/s FACE VE
L"
4480  MOVE Xmin+(Xmax-Xmin)*4/10,Ymax+(Ymax-Ymin)*2/60
4490  IF Plotter$="N" THEN MOVE 38.5,88.6
4500  LABEL USING "4D,X,K";Air_flow,"std l/s AIR FLOW"
4510  LORG 4
4520  MOVE Xmin+(Xmax-Xmin)/2,Ymin-(Ymax-Ymin)*8/60
4530  IF Plotter$="N" THEN MOVE 60,.6
4540  LABEL USING "K";Xname$
4550  LORG 4
4560  MOVE Xmin-(Xmax-Xmin)*1.1/10,Ymin+(Ymax-Ymin)/2
4570  IF Plotter$="N" THEN MOVE 5,47
4580  LDIR PI/2
4590  LABEL USING "K";Yname$
4600  IF Plotter$="N" THEN SETUU
4610  MOVE Xmin+(Xmax-Xmin)/20,Ymin+(Ymax-Ymin)/3
4620  LDIR PI/2
4630  LORG 3
4640  LABEL USING "K";Fam_name1$
4650  MOVE Xmax-(Xmax-Xmin)*1.5/70,Ymin+(Ymax-Ymin)/3
4660  LORG 1
4670  LABEL USING "K";Fam_name2$
4680  Flag1=1
4690  RETURN
4700  !
4710  END
```

APPENDIX C

EXAMPLE OF THE INTERACTION WITH THE COMPUTER TO PRODUCE THE REQUIRED GRAPHS

THIS PROGRAM WILL ASSIST WITH HEAT PUMP AND AIR-CONDITIONER DESIGN COMPRESSOR DATA MUST BE PREPARED BY PROGRAMME 'DATLOD' FROM IMPERIAL UNITS RESULTS ARE PRESENTED IN SI UNITS

P. Hawken Nov,1983 REVISION Aug 28,1984

```
DO YOU WISH TO USE THE 9872A AS THE PLOTTER?(Y/N)
Y
FILE NAME OF COMPRESSOR PERFORMANCE DATA FILE ?
CRG025
CONDENSER COIL TUBE SIZE,i.e. 10 OR 12 mm ?
10
No OF ROWS FOR CONDENSER COIL,i.e. 1 TO 6 ?
4
CONDENSER COIL ,No of fins per metre i.e.390,470,550 OR 630 ?
550
FACE VEL OF AIR TO CONDENSER COIL (m/s) ?
2.29
VOLUMETRIC FLOW RATE OF AIR TO CONDENSER COIL (sl/s) ?
425
EVAPORATOR COIL TUBE SIZE,i.e. 10 OR 12 mm ?
10
No OF ROWS IN EVAPORATOR COIL,i.e. 1 TO 6 ?
3
EVAPORATOR COIL ,No of fins per metre ,i.e. 390,470,550 OR 630?
390
FACE VEL OF AIR TO EVAPORATOR COIL (m/s) ?
1.68
VOLUMETRIC FLOW RATE OF AIR TO EVAPORATOR COIL (sl/s) ?
1416
```

```
COMPRESSOR:

          Compressor data file is CRG025

CONDENSER:
          tube diameter is  10  mm
           4  rows deep
           550  fins per metre
          air face velocity is  2.29  m/s
          air flow rate is  425  sl/s

EVAPORATOR:
          tube diameter is  10  mm
           3  rows deep
           390  fins per metre
          air face velocity is  1.68  m/s
          air flow rate is  1416  sl/s
IS SYSTEM SPECIFIED CORRECTLY (Y/N)?
Y


Maximum energy flow rate(kW) for ordinate,Ymax  (Ymin=0)?
18


SET UP PLOTTING LIMITS ON PLOTTER
ALLOW 5 MAJOR DIVISIONS ON THE HORIZONTAL AXIS
LENGTH OF VERT AXIS DEPENDS ON YMAX (YMIN=0)



CHANGE PAPER AND
SET UP PLOTTING LIMITS ON PLOTTER
ALLOW 5 MAJOR DIVISIONS ON THE HORIZONTAL AXIS



CHANGE PAPER AND
SET UP PLOTTING LIMITS ON PLOTTER
ALLOW 5 MAJOR DIVISIONS ON HORIZONTAL AXIS
LENGTH OF VERT AXIS IS AS BEFORE
```

APPENDIX D

EXAMPLE OF COMPRESSOR MANUFACTURER'S PERFORMANCE DATA SHEET

PERFORMANCE DATA

CRG1-0250-PFV/PFJ

208/230-1-60

265-1-60

- **PERFORMANCE CURVES - CENTERFOLD (A & B)**
- **PERFORMANCE TABLES - BACK PAGE (C)**

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FORM 90-48 A,B,&C-R1
SUPERSEDES 90-48A,B,&C

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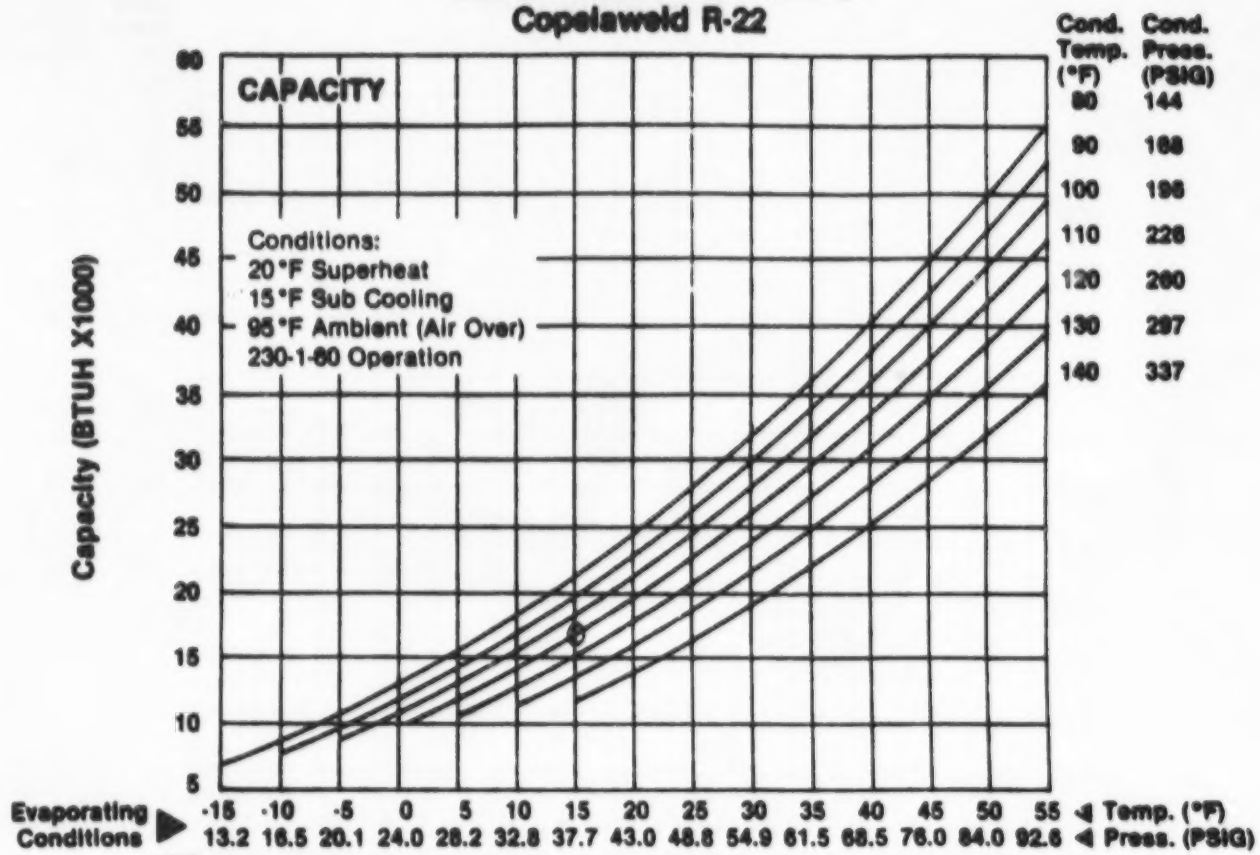
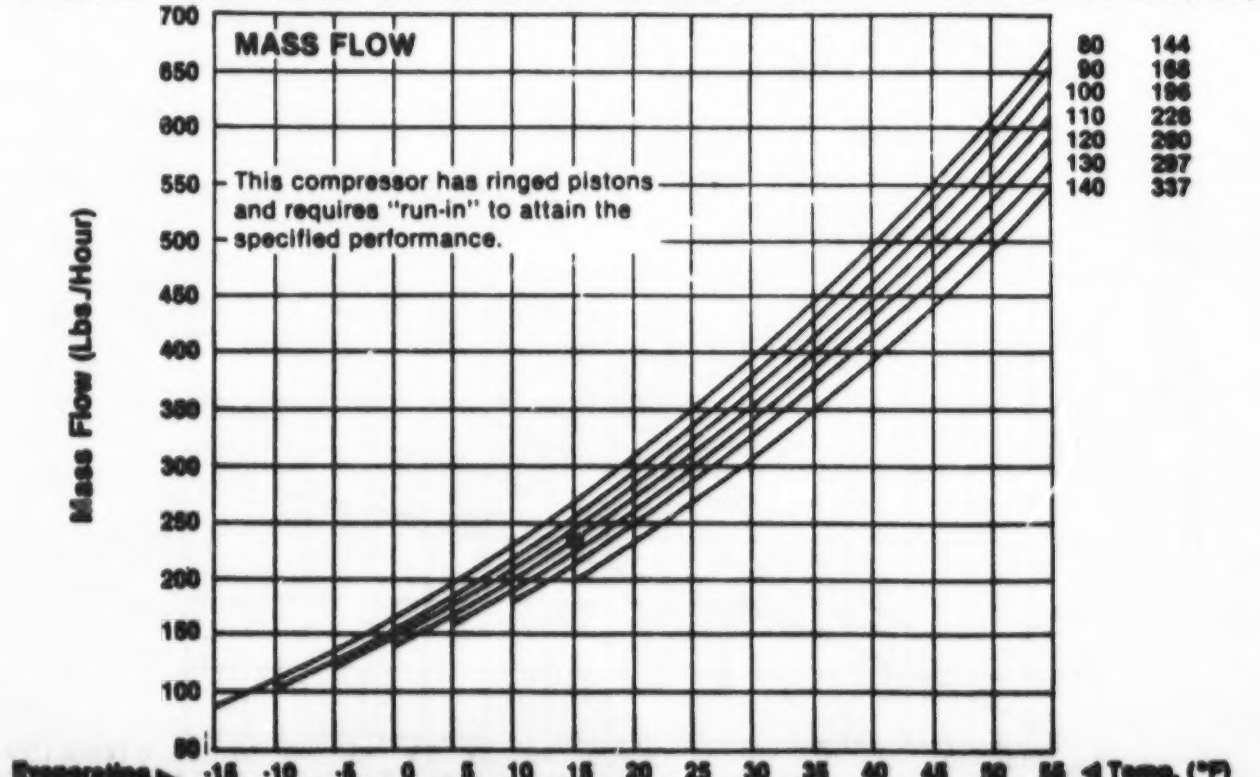
CRG1-0250-PFV/PFJ

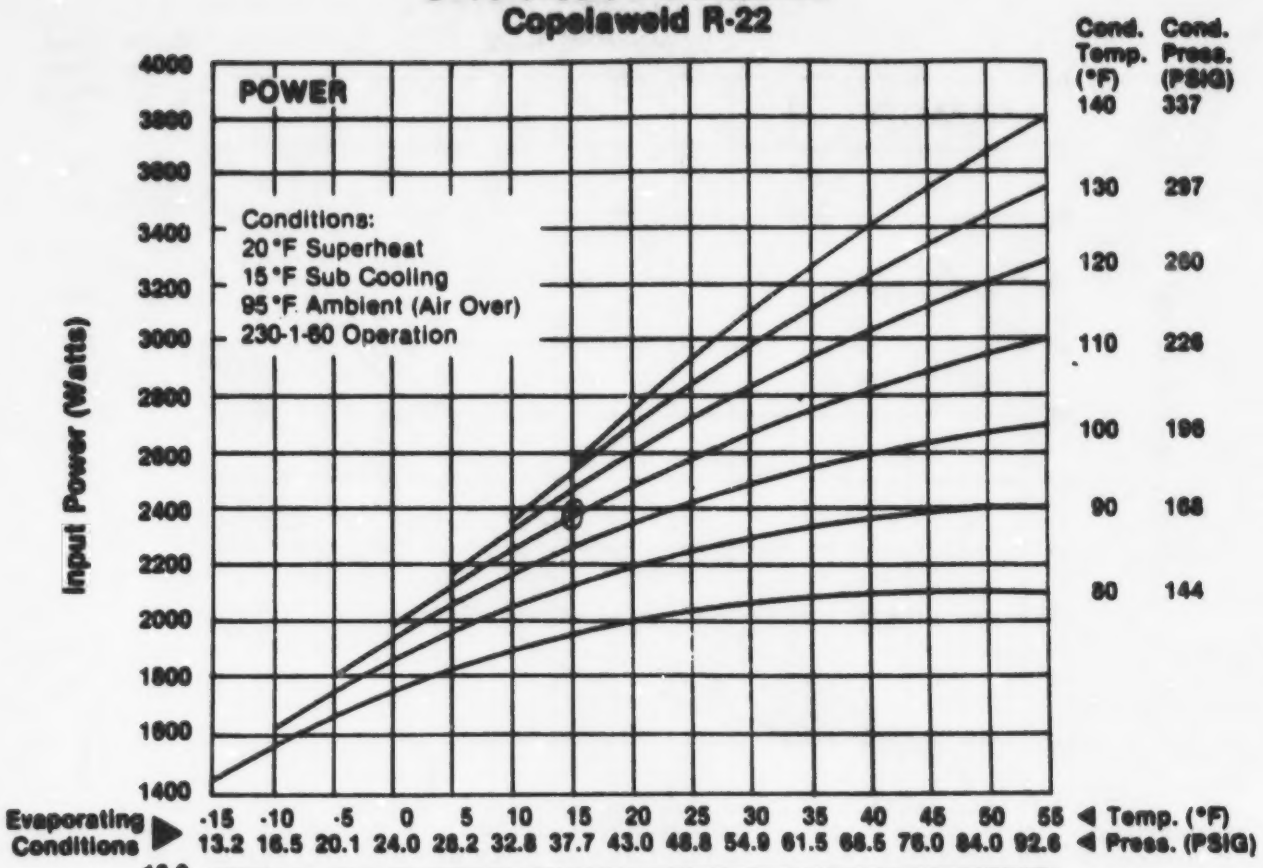
Copelaweld R-22

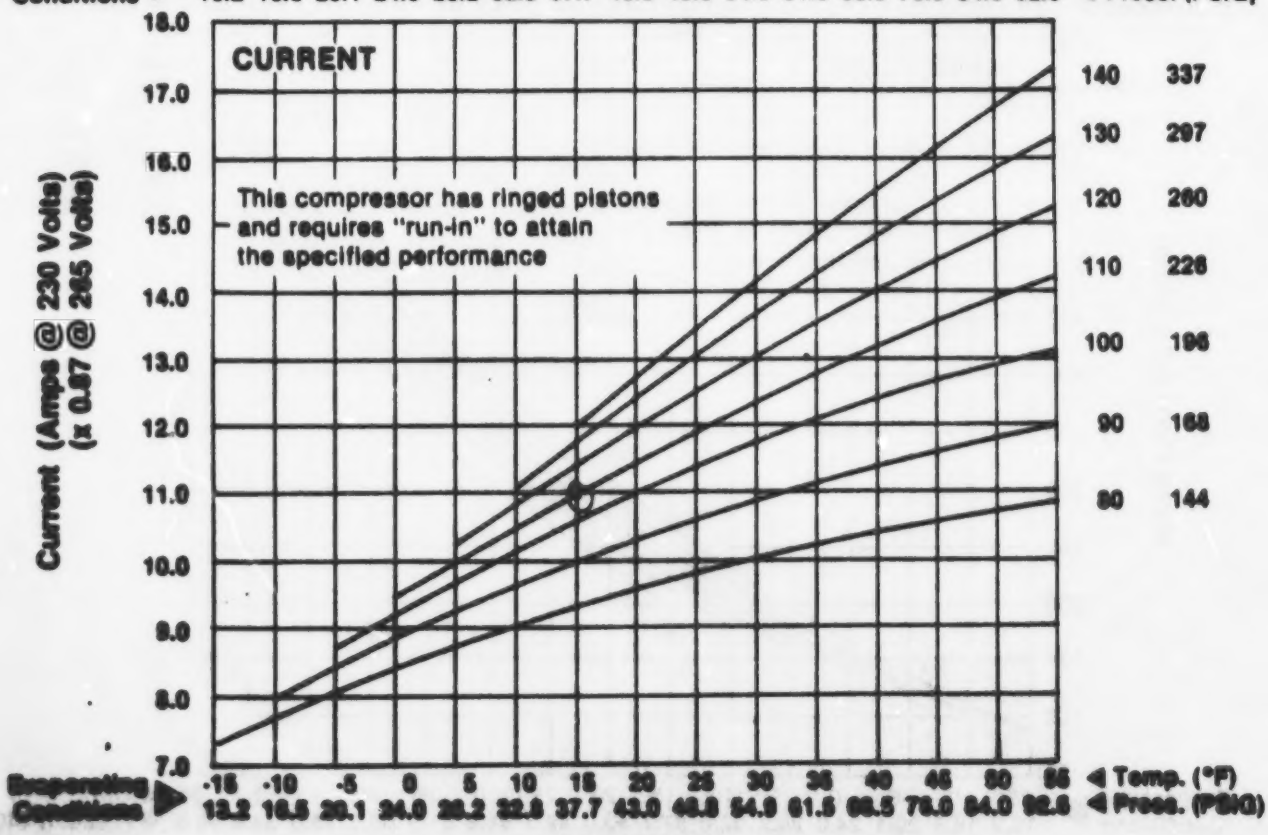




CRG1-0250-PFV/PFJ

Copelaweld R-22





CONDITIONS
20°F Superheat
15°F Sub Cooling
95°F Ambient (Air Over)
230-1-60 Operation

PERFORMANCE DATA

CR61-0250-PFV/PFJ
COPELAWELD® R-22
208/230-1-60
265-1-60

CAPACITY (BTU/HR)

CONDENSING TEMPERATURE	EVAPORATING TEMPERATURE -10	+0	+10	+20	+30	+40	+45	+50	+55
80	8561	12922	18185	24429	31740	40207	44903	49923	55279
90	7758	11898	16922	22907	29932	38082	42608	47448	52615
100	****	10852	15612	21308	28015	35814	40150	44790	49747
110	****	9783	14250	19627	25982	33393	37519	41938	46662
120	****	****	12834	17858	23826	30809	34703	38879	43346
130	****	****	11360	15997	21539	28050	31690	35598	39783
140	****	****	****	14036	19111	25106	28467	32081	35957

POWER (WATTS)

CONDENSING TEMPERATURE	EVAPORATING TEMPERATURE -10	+0	+10	+20	+30	+40	+45	+50	+55
80	1560	1743	1885	1988	2058	2096	2104	2105	2099
90	1626	1854	2035	2177	2282	2355	2380	2398	2409
100	****	1933	2159	2342	2487	2598	2642	2679	2709
110	****	1978	2254	2484	2672	2826	2891	2948	2998
120	****	****	2319	2599	2836	3036	3124	3204	3278
130	****	****	2351	2687	2977	3229	3342	3447	3546
140	****	****	****	2745	3094	3401	3542	3675	3801

CURRENT (AMPS) @ 230 Volts

Multiply Amps x 0.87 For 265 Volt Applications

CONDENSING TEMPERATURE	EVAPORATING TEMPERATURE -10	+0	+10	+20	+30	+40	+45	+50	+55
80	7.68	8.42	9.05	9.58	10.03	10.41	10.58	10.74	10.88
90	7.97	8.86	9.62	10.29	10.86	11.37	11.60	11.82	12.02
100	****	9.20	10.12	10.93	11.64	12.28	12.58	12.87	13.14
110	****	9.44	10.52	11.49	12.36	13.15	13.53	13.88	14.23
120	****	****	10.83	11.98	13.02	13.97	14.43	14.87	15.30
130	****	****	11.04	12.38	13.60	14.74	15.29	15.82	16.34
140	****	****	****	12.69	14.12	15.46	16.11	16.74	17.36

MASS FLOW (LBS/HR)

CONDENSING TEMPERATURE	EVAPORATING TEMPERATURE -10	+0	+10	+20	+30	+40	+45	+50	+55
80	100.97	163.56	228.30	304.22	392.37	493.85	549.95	609.82	673.59
90	102.77	156.12	219.50	293.90	380.35	479.95	535.03	593.81	656.44
100	****	148.42	210.28	282.99	367.57	465.07	519.01	576.58	637.94
110	****	140.43	200.62	271.47	353.97	449.15	501.82	558.06	618.01
120	****	****	190.48	259.28	339.50	432.11	483.39	538.16	596.56
130	****	****	179.85	246.39	324.08	413.89	463.64	516.79	573.48
140	****	****	****	232.74	307.67	394.39	442.47	493.85	548.66

Nominal Performance Values (±5%), Subject to Change Without Notice

APPENDIX E

CHARACTERISTICS OF HEAT EXCHANGERS AND TABLES OF CONSTANTS* USED IN PERFORMANCE CALCULATIONS FOR PLATE FINNED, AIR/REFRIGERANT HEAT EXCHANGERS

* The constants were calculated by polynomial regression fit of data obtained from McQuay, Inc., Minneapolis, Minnesota, "Engineering Manual", curves No. 2087 to 2095 and 2249 to 2365. The constants are used by equations (3) to (7) in the report.

Characteristics of Heat Exchangers

Copper tube

Tube wall thickness 0.41 mm (0.016 inch)

Aluminum plate fins, rippled and corrugated

Fin thickness 0.15 mm (.006 inch)

Tube pattern:

10 mm tube diameter - 25 mm x 22 mm staggered
(3/8 inch tube diameter - 1.0 inch x 0.866 inch staggered)

12 mm tube diameter - 32 mm x 27 mm staggered
(1/2 inch tube diameter - 1.25 inch x 1.08 inch staggered)

Table E1: Constants used in equation (3) for calculating the capacity per unit face area of a condenser 2 rows deep with an air face velocity of 2.54 m/s

TUBE SIZE mm	FIN DENSITY fins/m	a
10	390	1.0845
10	470	1.1753
10	550	1.2378
10	630	1.3003
12	390	1.1697
12	470	1.2435
12	550	1.3400
12	630	1.4195

Table E2: Constants used in equation (4) for calculating the face velocity/row number correction for the condenser capacity

TUBE SIZE mm	FIN DENSITY fins/m	#ROWS	b	c	d	e
10	390,470	1	0.61344	-0.33772	0.098790	-0.01085169
10	390,470	2	0.89220	-0.36105	0.085197	-0.00806222
10	390,470	3	1.15311	-0.43904	0.099698	-0.00890010
10	390,470	4	1.24683	-0.39947	0.084533	-0.0074:249
10	390,470	5	1.37857	-0.42337	0.092733	-0.00844702
10	390,470	6	1.37266	-0.38804	0.040024	-0.00073713
10	550,630	1	0.62870	-0.35334	0.104030	-0.01142679
10	550,630	2	0.87268	-0.33913	0.078049	-0.00740694
10	550,630	3	1.04661	-0.28829	0.039409	-0.00141422
10	550,630	4	1.26348	-0.42090	0.094839	-0.00885835
10	550,630	5	1.24752	-0.23852	0.010823	0.00065590
10	550,630	6	1.33169	-0.28596	-0.010041	0.00649564
12	390,470	1	0.56762	-0.25822	0.064540	-0.00635118
12	390,470	2	0.87608	-0.34354	0.079171	-0.00732075
12	390,470	3	1.00886	-0.43077	0.110232	-0.01076700
12	390,470	4	1.20169	-0.45245	0.113008	-0.01121987
12	390,470	5	1.25654	-0.49387	0.147792	-0.01714941
12	390,470	6	1.21453	-0.36194	0.100651	-0.01193597
12	550,630	1	0.63465	-0.34121	0.097081	-0.01043665
12	550,630	2	0.88567	-0.36265	0.087211	-0.00829421
12	550,630	3	1.12931	-0.50797	0.141453	-0.01509677
12	550,630	4	1.12031	-0.38944	0.092108	-0.00863867
12	550,630	5	1.22356	-0.48650	0.147205	-0.01694971
12	550,630	6	1.15949	-0.33882	0.092901	-0.01061399

Table E3: Constants used in equations (5)&(6)for calculating the capacity per unit face area of an evaporator 2 rows deep with an air face velocity of 2.54 m/s

TUBE SIZE mm	FIN DENSITY fins/m	f	j	k	l
10	390	0.81156	-22.528	-1.4198	-0.012337
10	470	0.88734	-24.638	-1.5573	-0.013494
10	550	0.92630	-25.752	-1.6282	-0.014320
10	630	0.96671	-26.891	-1.7028	-0.015106
12	390	0.79714	-22.200	-1.3939	-0.012068
12	470	0.85541	-23.830	-1.4996	-0.013054
12	550	0.90407	-25.135	-1.5848	-0.013828
12	630	0.95393	-26.524	-1.6731	-0.014459

Table E4: Constants used in equation (7) for calculating the face velocity/row number correction for the evaporator capacity

TUBE SIZE mm	FIN DENSITY fins/m	#ROWS	q	r	s	u
10	230-390	1	0.62870	-0.35334	0.104030	-0.01142679
10	230-390	2	0.95923	-0.44404	0.117738	-0.01214754
10	230-390	3	1.21476	-0.51173	0.129210	-0.01281514
10	230-390	4	1.32356	-0.45795	0.099148	-0.00852846
10	230-390	5	1.44850	-0.50883	0.120072	-0.01105139
10	230-390	6	1.39150	-0.26705	0.003203	0.00637161
10	470-630	1	0.63465	-0.34121	0.097081	-0.01043665
10	470-630	2	1.00037	-0.49337	0.136625	-0.01447782
10	470-630	3	1.09663	-0.39486	0.085906	-0.00737465
10	470-630	4	1.13425	-0.36035	0.094129	-0.01038650
10	470-630	5	1.13963	-0.27304	0.061881	-0.00713005
10	470-630	6	1.18888	-0.26657	0.062783	-0.00745018
12	230-390	1	0.73789	-0.45857	0.137959	-0.01532801
12	230-390	2	1.18010	-0.68243	0.204658	-0.02298301
12	230-390	3	1.51354	-0.89032	0.272021	-0.03112902
12	230-390	4	1.47752	-0.60018	0.191599	-0.02146342
12	230-390	5	1.47303	-0.57230	0.151202	-0.01658933
12	230-390	6	1.47628	-0.47151	0.114282	-0.01231256
12	470-630	1	0.77392	-0.58720	0.156987	-0.01755334
12	470-630	2	1.22264	-0.72947	0.221592	-0.02497559
12	470-630	3	1.47945	-0.82290	0.247306	-0.02789914
12	470-630	4	1.50528	-0.78860	0.229571	-0.02570944
12	470-630	5	1.50050	-0.58133	0.150950	-0.01653978
12	470-630	6	1.43317	-0.30094	0.016352	0.00338333

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A RELIABLE DESIGN AID FOR VAPOUR COMPRESSION CYCLE SYSTEMS

4

AUTHOR(S)/AUTEUR(S)

Hawken, P. J.; Lemal, C.

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Technical Report

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NOTES

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design; computer aided design; heat pumps; air conditioners; refrigeration; vapour compression systems; heat exchangers; compressors

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SUMMARY/SOMMAIRE

A design aid for sizing the major components of a vapour compression cycle system is described. This aid can be used by hand or with a desktop computer and plotter.

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ADDRESS/ADRESSE

T.R. Ringer, Head,
Low Temperature Laboratory,
Division of Mechanical Engineering,
National Research Council of Canada,
Montreal Road, Ottawa, Ontario.
K1A 0R6 (613) 993-2439

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